# Caterpillar Scope of Work for Environmental Project E-1
# Emission Reduction of Non-Road CI Engines (United States)

## Project Overview

On February 18, 2000, EPA approved Caterpillar's Plan to investigate, develop, field test and implement retrofit technologies to reduce NOx emission levels from Non-road Compression Ignition ("CI") engines. The primary focus of this project will be Non-Road CI engines operating in urban non-attainment areas. Caterpillar's proposal offers measurable short-and long-term emissions reduction.

Caterpillar will proceed to:

(a) Develop rebuild/retrofit kits that would convert unregulated engines to Tier I levels or below. Installation of these kits on existing equipment with Caterpillar engines will reduce emissions while maintaining or enhancing performance.

(b) Develop a program with local Caterpillar dealers in non-attainment areas to replace/relocate current equipment with newer lower emissions equipment. Caterpillar would offer subsidies or incentives to encourage customer and dealer participation in this program.

(c) Investigate early introduction of Tier II engines. Early introduction of Tier II engines would reduce emissions sooner than required by law.

(d) Investigate the development of black smoke reduction technology in Tier II and/or earlier engines. Such technology would have the goal of transparent smoke emissions and would further reduce emissions of these engines below regulated levels.

(e) Explore the feasibility of retrofitting Non-Road CI engine applications using Selective Catalytic Reduction technology. For example, an SCR package could be developed for use on an existing diesel/electrical generating unit. When paired with low sulfur fuels, these oxidation catalysts are expected to reduce emissions of nitrogen oxides (NOx), hydrocarbons (HC) and volatile organic compounds (VOC).

(f) Explore other new options to reduce emissions by developing and retrofitting existing Non-Road CI engines with advanced technologies such as EGR, advanced combustion systems or aftertreatment.

(g) Evaluate and implement appropriate methods to promote customer acceptance and rapid deployment of the kits into the field (including, where appropriate, discounting of the rebuild/retrofit kits). Appropriate technologies for each part of this proposal will be evaluated and selected in accordance with the criteria set forth in Exhibit II.

**<u>Project Implementation Plan</u>**

Phase I – Technology Assessment and Project Planning

Phase I – part (a): Identify Caterpillar Non-Road equipment that has high usage in urban non-attainment areas. Caterpillar will determine the probable future usage of this Non-Road CI equipment as well as (1) the complexity of adapting retrofit technologies to the subject engines and (2) addressing the issues to replace equipment or relocate equipment out of non-attainment areas.

Phase I – part (b): Document the potential applications where Tier II compliant engines can be introduced early. Evaluate the environmental impact gained from the NOx and PM reductions.

Phase I – part (c): Investigate opportunities for additional NOx reductions through the development and use of SCR aftertreatment technology. Caterpillar will investigate the modifications to engines, cooling systems and/or other emission system components that may be required for such a retrofit. Phase I will yield a list of potential tons of NOx reduction from Non-Road CI Engines in non-attainment areas and the associated costs. The goal will be to determine the cost effectiveness of reducing NOx through SCR aftertreatment.

Phase I – part (d): Explore other options to reduce emissions and/or black smoke in Tier II or earlier Caterpillar engines. Newer technologies, such as electronic controls, EGR, advanced combustion design, etc., will be evaluated for their application to these engines.

Phase I – part (e): Finalize the specific proposal for Phase II based upon the criteria set forth in Exhibit I. Identify potential sites in the Northeast and Midwest States for implementation of the selected programs.

Phase II – Technology Development

The most promising engine and/or aftertreatment technologies evaluated in Phase I will be developed in Phase II. Phase II will validate performance, reliability and durability of the design changes through appropriate laboratory or field tests. Phase II will also identify the hardware and/or software required to adapt the retrofit technology for Phase III field-testing and documentation.

Phase III – Field Testing and Documentation

The technology developed in Phase II will be field-tested on a calculated number of Non-Road CI Engine applications needed to fulfill the requirements of reliability and durability analysis. Caterpillar will record operating and maintenance data and perform periodic inspections of the equipment to identify any operational problems with the retrofit technology. The field-testing of the selected technologies will continue until sufficient operational hours demonstrate the total emissions, performance, and useful life results.

Phase IV – Implement Plan in Urban Non-attainment areas

Through discounts and other incentives, Caterpillar will help fund the procurement of the Non-Road CI Engine retrofit technology in non-attainment areas. To maximize the environmental benefits in a cost-effective manner, the areas will be analyzed for market potential and Caterpillar equipment availability. Caterpillar will target urban non-attainment areas nationwide, focusing on the Northeast and Midwest States to provide the greatest environmental impact from its selected programs.

## Expected Emission Reductions

Caterpillar plans to achieve approximately 1.1 tons avg./engine/year reduction in NOx emissions for the retrofit of Tier I parts on unregulated Cat equipment. Early introduction of Tier II engines will also result in 1.1 tons/engine/year NOx reduction. NOx reductions for other technologies evaluated will be estimated in the refined versions of the criteria matrix. The SCR retrofit on Caterpillar equipment is expected to achieve an estimated 3.0 tons/engine/year NOx reduction.

## Project Cost

At this time the total expected cost of $20.45 million for the proposal would be allocated as follows:

| | U.S. EPA | CA. |
|---|---|---|
| Phase I cost ---------- | $1.2 million | $0.5 million |
| Phase II cost --------- | $2.75 million | $1.0 million |
| Phase III cost -------- | $1.5 million | $0.5 million |
| Phase IV cost -------- | $9.0 million | $4.0 million |
| | ============ | ========= |
| Total Project Cost | $14.45 million | $6.0 million |

## Issues to Be Resolved for Project to be Successful

1. Insuring wide spread customer acceptance of retrofit kits.
2. Performance and durability issues resulting from equipment with retrofitted engines. (For example; torque rise, cooling, response, fuel consumption, etc.)
3. Whether SCR can be adapted to unregulated engines without electronic governing.
4. Durability of SCR in a mobile off-road application.
5. Feasibility and availability of low sulfur fuel to support SCR retrofits.
6. Establish certification process for retrofit kits.
7. Determine feasibility of packaging EGR into existing mobile equipment.

# Caterpillar Scope Of Work For Appendix E-2
# Hybrid Engine System Development Project

## Project Overview

On February 18, 2000, EPA approved Caterpillar's Plan to evaluate, develop and demonstrate hybrid regenerative powertrain technology for on-highway heavy-duty vehicles. Caterpillar will (1) demonstrate emissions levels on a gram per mile basis equivalent to 1.0 g/bhp-hr NOx + NMHC and 0.05 g/bhp-hr PM in a conventional vehicle, (2) improve performance and fuel economy compared to conventional vehicles, and (3) reduce $CO_2$ emissions compared to conventional vehicles. This multi-part goal is intended to be environmentally beneficial with the potential for high market acceptance and demand.

## Project Implementation Plan

## Phase I – Technology Assessment

This phase will consist of parallel evaluations of two hydraulic powertrain technologies and one electric hybrid engine. This parallel approach will allow for evaluation and comparison of ultra efficient, regenerative braking transmission technology and efficient, ultra low NOx emissions engine.

### Phase I – part (a) Hydraulic Drive Train

Caterpillar will perform a vehicle level optimization to efficiently and cost effectively apply full hydraulic drive and diesel engine efficiencies without a mechanical drive train using standard hydraulic components in a Caterpillar proprietary "Dynasty" simulation. This Phase I simulation will (1) evaluate the performance and efficiency in a standard EPA cycle of a vehicle driven by hydraulic energy that is then recuperated in accumulators during vehicle braking, (2) develop appropriate component sizing recommendations for accumulators, motors and lines based upon desired fuel consumption reduction, and (3) evaluate control schemes for optimum performance.

**Phase I – part (b) HCCI, Hydraulic Free Piston Engine**
Concepts for improved size, weight, cost, efficiency, reliability and durability will be validated on the existing free piston engine. New combustion system concepts evaluated will include an injection characteristic study with differing fuel nozzles, different scavenging design for compactness and a high temperature/low heat rejection piston. A simplified hydraulic control system will be evaluated for improved performance, starting characteristics and reliability. Finally, there will be a fundamental study of fuel delivery systems required promoting HCCI combustion for diesel and gasoline.

**Phase II – Systems Testing**

Based on the results of Phase I – part (a), Caterpillar will select the most promising technology and will build a test bed to evaluate system performance, emissions, efficiency, noise and reliability.

**Phase III – In Engine/In Vehicle Testing.**

**A. Phase III – part (a) Hydraulic Drive Train Development**
A vehicle will be selected for conversion to a hydraulic drive system and tested for performance, efficiency and noise. This system will be in accordance with the best solutions from Phases I & II, including most efficient and lowest emissions engine drivetrain configurations.

**B. Phase III – part (b) Emissions Testing**
The converted vehicle will be tested on a chassis dynamometer to evaluate the impact on real world, in-use emissions.

**Phase IV – Field Testing.**
The best of the hydraulic hybrid engine and drive train concepts (based on the criteria set forth in Exhibit II) will be field-tested for one year.

**Expected Emission Reductions**

The combination of a free piston engine and the hydraulic hybrid system is expected to reduce NOx emissions by 220 tons per year for every 1 million vehicles.

A hydraulic hybrid system with a conventional internal combustion engine is expected to reduce NOx emissions by 130 tons per year for every 1 million vehicles.

These emissions estimates are based on reducing average power from 30hp to 20hp with the hydraulic hybrid system and 2000 hours/year vehicle usage.

**Issues to Be Resolved**

Caterpillar will seek leveraged funding, and other partnering opportunities, to complement its commitment to this project. Caterpillar has already begun to explore such opportunities with automotive companies, hydraulic component suppliers, Sandia National Laboratories under a CRADA, the Department of Energy and the Department of Defense. Successful completion of this project is contingent on obtaining leveraged funding.

The technical challenges in this project are significant and success is not guaranteed.

# Caterpillar Scope of Work for Environmental Project #4: On-Highway CI Engines Emission Reduction

**Project Overview**

On February 18, 2000, EPA approved Caterpillar's plan to evaluate, select, develop and demonstrate advanced combustion and aftertreatment technologies for on-highway Heavy Duty Diesel Engines (HDDE) that would reduce emissions levels of NOx and PM substantially below the requirements of October 2002 regulations. The goal of this project is to demonstrate the feasible range of emissions reduction achievable for the next generation of environmental regulations. The project will lead in the direction to quantify the unregulated emissions and to develop technologies that will be reliable and durable while minimizing the fuel consumption penalties associated with present aftertreatment devices.

Caterpillar will evaluate and select candidate suppliers of the most promising commercial aftertreatment devices in order to form productive partnerships to develop products to meet future emission goals and market demands of diesel truck engines. This project should minimize development costs and obtain the optimum gain in technology by combining the suppliers' knowledge of the construction and materials of the aftertreatment devices with Caterpillar's diesel engine technology and research resources.

**Project Implementation Plan**

Caterpillar's C-12 heavy-HDDE and the 3126 medium-HDDE families will serve as engine platforms for development. The technologies thus developed will be applicable to all Caterpillar engines for on-highway applications. It is the objective of this program to:

(a) demonstrate the technical feasibility of meeting the NOx "emission goal" of 0.5 g/bhp-hr and the PM emission goal of 0.01 g/bhp-hr;

(b) demonstrate the technical feasibility of meeting the NOx "emission stretch goal" of 0.2 g/bhp-hr and the PM emission goal of 0.01 g/bhp-hr;

(c) develop the most cost-effective emission control technology that yields the best owning and operating cost for the truck customers;

(d) quantify technology capabilities and determine emission goals that can be met cost-effectively;

(e) work closely with suppliers, outside consultants, universities, national laboratories and government agencies to develop the best emission control technologies and to expedite technical and commercial development. The goal is to bring the product to the marketplace at the earliest possible date.

The development program consists of three phases. The development objectives and the scope of work for each of the three phases are described below and in the attached Gantt chart

This project will have both the emission goal and the emission stretch goal shown in (a) and (b) above. Together, they will be referenced as the "emissions goal" in the remainder of this document.

Phase I - Technology Assessment and Project Planning

Caterpillar will conduct an extensive search and preliminary evaluation of the existing aftertreatment products currently available either on the market or in research and development stages. This search will identify potential suppliers and products that could be evaluated for adaptation to heavy-duty and medium-duty diesel engines in on-highway applications.

Caterpillar will create a supplier comparison chart to evaluate the most technologically advanced suppliers. Caterpillar will then proceed to formulate a working relationship with the selected suppliers to conceive designs and testing procedures for the advancements needed to produce an economical and reliable emissions reduction system for diesel engines.

During Phase I of this proposal, Caterpillar will also seek the input of outside consultants, universities and national laboratories concerning emerging emissions reduction technologies. Caterpillar will also investigate leveraged funding opportunities from different State and Federal government agencies to maximize the development effort and identify the most suitable development partners.

As an output from Phase I, a more detailed scope of work may be formulated for the Phase II development activities.

## Phase II – Building-block Technology Development

Phase II will focus on developing the most promising component technologies for production. The viability of each technology will be evaluated using, at a minimum, a set of acceptance criteria.

To facilitate efficient project management, the Phase II building-block technology development activities will be grouped into the following five "sub-projects":

- 2.1 SCR Technology Development
- 2.2 NOx Adsorber Technology Development
- 2.3 DPF Performance and Durability Demonstration
- 2.4 Combustion Technology Development
- 2.5 Combined Low NOx/Low Particulate Technology Demonstration

Each sub-project will initially move forward and then be evaluated periodically (scheduled to minimally be every six months) against the acceptance criteria matrix (Exhibit 1). Depending on the level of success that begins to develop as work progresses on these sub-projects there may be redirection of the focus of the overall project. The most promising projects will continue to receive effort and progress forward based upon the acceptance criteria matrix.

### Sub-Project 2.1 - SCR Technology Development

SCR (Selective Catalytic Reduction) technology is well established for NOx emissions reduction from stationary sources. Unlike stationary applications, however, application on mobile diesel engines presents a host of additional engineering, regulatory and customer acceptance constraints.

The overall objective of this phase of the project is the thorough investigation of mobile SCR technology. A complete understanding of the technical, economic, and consumer aspects of the technology will be developed. Within the scope of this work the overall emission reduction levels that are achievable with mobile SCR will be determined. In addition, the following tasks will be undertaken to address other highly important technical objectives.

*2.1.1 - Catalyst Performance/Deterioration Trade-Offs and Unregulated Emissions*
The performance of the current generation SCR catalyst material technology will be evaluated through bench testing and/or testing on an engine. In addition, "next-generation" materials and/or SCR system concepts will be solicited from catalyst suppliers for evaluation. Caterpillar will work closely with suppliers to advance the technology for mobile application. Emissions reduction performance, resistance to thermal and chemical deterioration, and

detectable unregulated emissions (i.e. $N_2O$, $NH_3$, etc.) will be quantified and assessed under steady-state and transient test conditions.

*2.1.2 - Reductant Issues*

Caterpillar will investigate aqueous urea injection systems. Single fluid vs. two fluid (i.e. air-assisted) injection designs from suppliers, if suitable for application on on-highway truck engines, will be evaluated. In addition to the implications that an air-assisted design will have on vehicle application, the complications associated with cold weather use and its impact on system design will be investigated. Results from the Advanced Petroleum Based Fuels – Diesel Emissions Control (APBF-DEC) program will be used for this evaluation work. Material compatibility effects (i.e. corrosion/degradation) of aqueous urea on injection systems as well as downstream components such as exhaust piping and mufflers will be examined. Solid reductant ammonia sources, as an alternate to aqueous urea, and their associated delivery systems will be considered since this could eliminate the cold weather and infrastructure drawbacks currently associated with SCR. This aspect of the reductant issue will be undertaken in more depth in Sub-project 2.5 (described below).

*2.1.3 - System Controls and Anti-Tampering Strategies*

Strategies for controlling the SCR aftertreatment system during transient engine operation will be explored to understand the maximum achievable NOx reduction performance limits over the approved test cycles. Current as well as “next generation” sensor technology will be evaluated. The limits of sensor response times will be investigated to determine methods for effective closed-loop feedback control and its effect on achievable SCR system performance. Incorporated within the control strategy work will be refinement of currently proposed anti-tampering strategies.

Based on Phase II test results an assessment will be made on the merits of SCR technology warranting continued development as a cost-effective aftertreatment system capable of meeting the target emission goals for on-highway truck engines.

**Sub-project 2.2 - NOx Adsorber Technology Development**

NOx adsorbers are currently being viewed by many people as an emerging technology that may be promising for achieving high levels of $NO_x$ reduction in lean burn engine applications. However, there are significant inherent challenges for application of this technology to heavy duty diesel engines with their temperature and regeneration requirements at any point on the high BMEP torque map. With this technology, NO is first converted to $NO_2$, then the $NO_2$ is stored by reaction with an alkaline earth sorbent to form the solid nitrate. Frequent regeneration of the NOx adsorbing catalyst is needed, in which there is a reduction step requiring rich conditions in the exhaust. The reductant (e.g. CO, $H_2$) releases and reduces the stored $NO_{x,}$ and converts it to $N_2$ over a precious metal type catalyst. Very high $NO_x$ conversion efficiencies, around 90%, have been demonstrated under ideal system conditions. In practical systems, however, the range of operating temperature tends to limit the overall efficiency of NOx conversion. Additionally, the presence of sulfur (from the fuel and lube oil), even in very low concentrations (tens of ppm) poisons NOx adsorber systems because sulfur oxides and the alkaline earth sorbents form very stable sulfates. For this technology to be commercially viable for heavy duty diesel engine applications, the fuel sulfur will need to be reduced to near zero levels. Additionally more sulfur tolerant catalyst formulations will need to be developed.

The overall objective of this sub-project is to establish the technical viability of the NOx adsorber technology. An investigation of regulated and unregulated emissions performance, impact on engine performance, durability, reliability, packaging, and truck owning and operating costs will be conducted. Caterpillar will work closely with suppliers to assist them to advance the state-of-the-art of the NOx adsorber catalyst technology. Work will fall into two main tasks: development of a regeneration system/strategy (task 2.2.1) and evaluation of promising NOx adsorber technology formulations from suppliers (task 2.2.2)

*2.2.1 - Regeneration System/Strategy*

NOx adsorbers require a rich environment for regeneration (desorption and subsequent reduction of NOx to $N_2$). Different approaches for achieving rich conditions will be examined and evaluated to arrive at development of a suitable system/strategy that can be used effectively with NOx adsorber technologies while meeting a suitable level of viability as determined by the acceptance criteria (described earlier). It is anticipated that there may be significant increase in HC, CO, and particulate matter emissions as a result of the strategy employed with regeneration of NOx adsorbers. Additional aftertreatment, such as a diesel particulate filter (DPF) may end up being required. An assessment of the need for a DPF will be made.

*2.2.2 - NOx Adsorber Evaluation*

Using the engine with the developed regeneration system/strategy, promising NOx adsorber formulations from suppliers will be evaluated. As possible, improvements will continuously be made to the regeneration system/strategy to minimize fuel consumption impact and formation of potential unregulated emissions. Feedback to associated catalyst suppliers will occur regularly to aid them in development of improved NOx adsorber formulations.

**Sub-Project 2.3 – DPF Performance and Durability Demonstration**

The objective of this sub-project is to evaluate passively regenerated diesel particulate filter (DPF) technologies. The filtration efficiency and the ability for self-regeneration of these DPF devices have been investigated in engine laboratories. However, the durability of these DPF devices has yet to be proven for the wide spectrum of applications to which they may be applied for HHDDE and MHDDE use. The goal of the project is to understand the performance and generate durability data on the passive DPF technologies.

*2.3.1 - Performance Issues*

On an as-needed basis, existing data on the performance of passive DPF technologies will be supplemented with additional on-engine evaluation (either lab or in-vehicle testing). Issues related to sizing, pressure drop, installation requirements/constraints, cold environment operation, etc. will be assessed in order to develop a more complete understanding of all the issues affecting the overall performance of this particulate reduction technology.

*2.3.2 - Durability Evaluation*

Beyond initial system performance, issues associated with real-world durability (deterioration, plugging, effect of fuel sulfur, etc.) will be assessed for the passive DPF technologies. Durability data with test samples exposed to expected future specification fuel (i.e. less than 500 ppm sulfur) utilizing test engines will be gathered and evaluated.

**Sub-Project 2.4 - Combustion Technology Development**

The goal of this sub-project is to develop a combustion system that minimizes the engine out emissions. Aftertreatment solutions alone for emissions reduction are projected to be costly and their use could cause truck buyers to postpone new truck purchases and thereby delay the environmental benefit of the lower emissions engines. By minimizing the engine-out emissions, the size and cost of the aftertreatment system will be minimized, avoiding the delay in engine purchases and maximizing the overall benefits to the environment and public. Homogeneous Charge Compression Ignition (HCCI) offers the potential for in-cylinder minimization of engine emissions.

The approach to this sub-project consists of three technology development tasks, two in parallel and a system optimization as the third. The first task (2.4.1) involves demonstration and control of the HCCI process itself. The second task (2.4.2) undertakes development of systems to deliver proper mixtures of fuel and provide the necessary control of the combustion. The third task (2.4.3) is to select and incorporate the best systems for achieving HCCI, develop controls, and perform system optimization to achieve demonstration of the emissions goal with acceptable fuel consumption. If acceptable, the system will be demonstrated in a truck application, with suitable aftertreatment technology incorporated as needed (as part of Phase III).

*2.4.1 - Basic HCCI Operation and Control*

Caterpillar will design and develop a single cylinder engine with multiple injectors to achieve the HCCI process. Methods of combustion control will be investigated and may include but not be limited to injection rate, variable valve timing, variable compression ratio, and exhaust gas recirculation (EGR). The region of true HCCI operation will be expanded using these control methods. Mixed mode operation where there is a portion of the fuel in the HCCI phase as well as a conventional diesel combustion phase will be used to increase the power density over that achievable with HCCI alone. Proper HCCI operation will provide a more ideal combustion rate improving fuel efficiency by avoiding the late burn associated with timing retard for $NO_x$ control or the slow burn normally associated with EGR. Various modeling methods including 3D-combustion simulation and 1D thermodynamic system analysis will be developed and employed. The development of such models will be aided by Caterpillar's relationships with leading universities (such as the University of Wisconsin) and national labs (such as Sandia and Lawrence Livermore). Caterpillar will engage its own optical access engine to study and understand the HCCI process and improve the models.

*2.4.2 - Fuel and Control Systems Development*

Caterpillar will, in conjunction with its Fuel Systems commercial business group, develop a single injector (or other compact system) to create the HCCI and mixed mode operation and develop mechanisms to achieve variable valve operation, EGR, etc. that are required for control. The commercial viability of HCCI hinges on creating a compact system that fits within the current engine compartment of heavy-duty trucks, and its deployment would be hastened by a system that fits within cylinder heads with a minimum of modification.

*2.4.3 - System Incorporation and Optimization*

Caterpillar will down select the one or two most commercially viable concepts for the fuel injection system and determine which of the control mechanisms are most effective and viable. These concepts will be incorporated into a multicylinder engine design and be built. This engine will then be used for further development and system optimization and to demonstrate capability of achieving the project emissions goal while meeting the technology assessment acceptance criteria. Caterpillar is seeking to develop an HCCI system that will be acceptable to the marketplace. Additional systems that may be investigated include unique combustion chamber geometry's to create air motion to control burning rates and thereby reduce emissions. The injection rate shape flexibility of Caterpillar fuel systems will be employed to optimize these systems. New injector designs will be created as needed to exploit the improvements in combustion.

**Sub-Project 2.5 - Combined Low NOx/Low Particulate Technology Demonstration**

The main objective of this sub-project is to generate catalyst and DPF durability data through field testing while demonstrating the combined technology capability to meet the emissions goal. An important part of this sub-project will be communication with truck OEM's to identify and understand the issues required for optimal system packaging and installation. If one or more of these technologies become a down-selected component of the final emission control system, the success of this sub-project will ultimately lead into the System Integration (Phase III) portion of this project.

For this sub-project, Caterpillar plans to explore the possibility of obtaining leveraged funding from State funding organizations (such as CEC). It is anticipated that there will be a need to work in partnership with a truck OEM, an oil company and major component suppliers to develop and demonstrate the technology. An alternative approach being explored is coordination of some portion of this work under the auspices of the APBF-DEC program.

The emission control system under consideration consists of a combination of the passively regenerated particulate filter, SCR, and advanced EGR. While urea solution has been successfully used as reductant for SCR systems in stationary applications, it poses difficulties in the mobile application. The need for urea distribution infrastructure, extra weight to be carried on-board the vehicle, freezing of the solution, etc. are all issues of concern. A more appealing source of ammonia for the mobile SCR application may be solid reductants (e.g. ammonium carbamate). Currently, there are several solid reductant delivery systems under development in Europe. Caterpillar will select the most promising solid reductant delivery system and assist the supplier to develop the system for commercialization. In the event that issues continue to remain with the solid reductant delivery systems that make them non-viable and prevent their use, a urea solution reductant delivery system will be considered as a back-up system.

Achieving the emissions goal will require the test engine with the lowest engine-out NOx. The best available technology to date is the "cooled EGR". In this sub-project, different EGR concepts will be explored with the objective of identifying the most cost-effective EGR system which will be used for the test work. Additionally, Caterpillar will work with the sensor suppliers to evaluate the sensor technology for emission control and on-board diagnostics (OBD). The field testing in this program will offer an opportunity to test out various concepts to discourage tampering of the emission control system.

Phase III – System Integration

The information generated in the Phase II sub-projects will be analyzed. Based on analysis of the results, the combination of component technologies which have demonstrated their ability to achieve the emissions goal while also satisfying the assessment criteria will be down-selected as the final emission control system. Optimization of the final emission control system would be planned to be performed in an engine test laboratory and/or on a test truck. The testing will be used to demonstrate performance as well as to gather some extended operation data of the complete emission control system with the purpose of evaluating its ability to meet the critical acceptance criteria in a satisfactory manner.

## Project Cost

At this time, Caterpillar anticipates that the total estimated project cost of $8.75 million would be allocated as follows:

Phase I cost ---------- $ 1.00 million
Phase II cost --------- $ 7.50 million
Phase III cost -------- $ 0.25 million
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**Total Project Cost: $8.75 million**

## Expected Emission Reductions

If the NOx emission goal of 0.5 g/bhp-hr is achieved it is anticipated that the NOx emissions from a typical on-highway heavy duty diesel truck engine will be reduced by approximately 1.1 tons avg./engine/year (assuming a 2002 baseline level of 2.5 g/bhp-hr).

With their differences in power ratings and average driving conditions, NOx emissions will be reduced by approximately 0.22 tons avg./engine/year for medium duty diesel engines. For both engine classifications, achieving the stretch goal of 0.2 g/bhp-hr results in a 15% greater amount of reduced NOx emissions.

If the particulate emission goal of 0.01 g/bhp/hr is achieved, the expected particulate emissions reduction will be approximately 0.05 tons avg./engine/year for heavy duty diesel and 0.01 tons avg./engine/year for medium duty diesel engines.

## **Issues to Be Resolved**

The basic issues related specifically to the success of the project are discussed within the body of the Statement of Work. However, the key issues that may likely need to be resolved in order for the outcome of this project to ultimately lead to a successful implementation include:

1. Wide spread public availability of appropriate concentration level ultra-low sulfur fuel to enable successful utilization of NOx adsorber technology and passive DPF technology.
2. A urea infrastructure for viability of urea SCR technology.
3. Demonstration of the final emission control system's ability to meet the minimum acceptable durability/reliability targets for on-highway heavy duty diesel engine use.
4. Widespread customer as well as regulatory body acceptance of the final emission control system.